Comparison of US and European Airports and Airspace to Support Concept Validation

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1 Executive Summary

Both the Federal Aviation Administration (FAA) and EUROCONTROL are developing operational concepts for ATM in the 21st century. Recognizing that aviation is a global activity, both communities acknowledged that a harmonized path toward modernization would greatly benefit both the users and service providers. To this end, a joint activity for concept development and validation was proposed, accepted, and sponsored by the FAA and EUROCONTROL Research and Development (R&D) Committee. The first activity undertaken, a high level comparison of the two operational concepts, found many similarities and agreements. A key concern coming out of that comparison was assurance that the descriptions are actually describing comparable environments. A follow on activity was proposed to compare the detailed operations of US and European airports and airspace.

The data gathered to support this activity would sharpen ideas and, where necessary, correct erroneous notions by shedding light on the similarities and differences between our current operations. Understanding these similarities and differences will support modernization efforts and enable joint participation on future concept development, validation, and implementation.

2 Background

Both users and service providers recognize that modernization is essential to assure that Air Navigation Services can meet the predicted growth of aviation activity. Given the rate of growth and the increasing inability of the current operations to meet that demand, actions must be taken today, including enhancements to procedures and infrastructure, and fielding new technologies, to support controller and pilot operations.

Based on their respective operational concepts, the FAA and EUROCONTROL are independently developing and jointly coordinating strategic plans to modernize European and US airspace. These strategic plans outline the requirements of the service providers for safe and efficient operation of their respective airspace.

Recognizing that aviation is a global activity, harmonization between the US and Europe is important to ensure a seamless transition from one airspace to another. For this very reason, the FAA and EUROCONTROL are also working with the International Civil Aviation Organization (ICAO) to contribute to the global operational concept.

A first step to assure harmonization is to use joint concept development and validation activities. This requires identification and normalization of metrics and measures that could be applied to both European and US operations that would enable common conclusions to be derived. The need for such a comparison arose because, although the concepts in the US and Europe sound quite similar, and the adjectives - *dense, complex, busy*, etc. - are the same, there is little, short of measurement, to assure the concepts are talking about similar environments and similar problems. This paper will describe the assessment territory, measures and metrics, and findings.

3 The Assessment Territory

Core airspace areas (see Figure 5 and Figure 6) have been selected to represent the most typical problems of the highest traffic density on both sides of the Atlantic. It is in those environments that we can best understand how current concepts can deliver today's performance and the challenges the expected traffic growth will present.

The busy traffic areas are generally of the same size though the concentrations of major airports appear denser in Europe. The similarities extend to raw traffic statistics. At the 1997 conference the European members reported that average IFR flight length within the ECAC countries was 470 nautical miles and 1 hr and 20 minutes in duration. The US participants reported similar numbers for the US - 470 miles and 1hr and 23 minutes in duration. It was the appearance of similarity and not difference that helped initiate this comparison.

4 Metrics and Measures

The measures and metrics developed for this activity describe operations and not the more customary values of delay. The goal is to match like with like as much as possible in terms of traffic needs and problems to be solved. Once this is achieved, the next step is to look at procedures and performance. To this end, the assessment looks at characteristics such as fleet mix, operations per day, peak operations, individual user penetration (percentage of flights), average transit time, average sector size, average staffing, etc.

5 Assessment and Findings

5.1 Airports Assessment

Several airports within the core airspace were selected for the comparison exercise. Understanding today's limitations, operations, and business paradigms for these airports will enable service providers and users to plan for transition and implementation of future operational concepts for national and global airspace systems.

5.1.1 Airports Activities and Operators

In the US, the aviation system is a hybrid system of hub-and-spoke and point-to-point (direct) services. The major carriers in the US all operate large hubs. The general characteristics of hub and spoke are:

- One or two carriers are the dominant operators at a major airport.
- Observation of airport traffic shows a bank of aircraft arriving within a time period, followed by a bank of aircraft departing at 45 – 60 minutes after the arrival bank.

In Europe, the hub-and-spoke business paradigm is not yet as prevalent. Even so, the data reflects airline domination (percentage of activities) at the major European airports. This is a legacy of regulation and has not changed significantly. For example, in the United Kingdom (UK), the major operator at the two primary airports (London Heathrow and London Gatwick) is British Airways (BAW). Similarly, for Schiphol Airport, Koninklijke Luchtvaart Maatschappij (KLM) is the dominant operator. In France, the major air carrier at Charles De Gaulle (CDG) is Air France (AFR). Thus, the national operator for the country is still the major operator at the country's major airport(s). Those airlines developing hubs do it first at these historical bases.

Table 2 reflects major operators at selected European and US airports. At some of the top US airports, for example, at the hub airports such as Chicago O'Hare (ORD), Atlanta (ATL) and New York Newark (EWR), over 50% of the traffic is due to one or two carriers.

The data in Table 3 compares traffic at US and European airports. The percentages of heavy aircraft reflect the transatlantic/long haul activities while the medium aircraft type reflect flights within the European or US continent. In both areas there is a high proportion of medium aircraft. This may indicate the aircraft type is based on the length of the city pairs. There is no evidence of using heavy aircraft to increase the passenger carrying capacity of each slot.

5.1.2 Airport Capacity, Configuration, and Movements

In Europe and the US, each airport publishes a declared capacity based on airport infrastructure (e.g., runways), supporting airspace and other variables (e.g., staffing and negotiation). The shared understanding is that declared capacity for the airport in Europe is based on IMC operation, while the declared capacity for the US is based on VMC operation.

Consider first the relationship between capacity and delay. Delay is a decision variable in scheduling in both the US and Europe. In Europe, unlike most airports in the US, the number of slots provided at an airport is the subject of negotiations between the airport and carriers, and is based on the acceptable level of delay, political, and environmental consideration. Airports such as Heathrow will have higher "planned" delays by providing a larger number of slots. Carriers accept the delay performance as a trade-off to access. The sense that capacity (slots) is both a technical and political consideration extends to the US as we note the current political struggle over slots at Washington's Ronald Reagan National Airport (DCA), where the number of combined GA and commercial slots often exceeds the capacity provided on a scheduled basis.

In the US, other than the four slot controlled airports - Chicago's ORD, Washington's DCA, and New York's LGA and JFK airports, the users' business cases and their relationship to delay are major contributors to scheduling but not the declared capacity. The users adjust their schedules to delay performance. Increased delays can lead to both changes in block times as well as changes in number of operations scheduled. It is clear that the marketplace provides schedules that are more susceptible to disruption of service due to weather, but in the end the schedule is again a function of trading access with delay. The explicit negotiations in the European process may result in choosing points lower on the knee of the delay curve.

The methods for measurement of capacity declaration need also to be examined. For instance, as related in a paper by Frederic Rico, the Director of Air Traffic Operations, Aéroports de Paris, Charles De Gaulle Airport's declared hourly capacity in 1996 was 84 while the peak hourly rate was actually as high as 106.[1] This is the difference in measuring the schedule from n:00 to n+1:00 and capturing the peak sliding 60 minute throughput. In addition, the Rico paper makes a point that while the declared capacity is set by several factors, the capacity the airport operators are working to achieve through both airspace and airport initiatives is the fair weather capacity. This allows the flexibility associated with the "sliding window" operations.

A related factor is environment. Are other airports in close proximity and are there dependencies between these airports? For instance, the ATM Constraints paper shows that the Charles De Gaulle Airport's declared capacity went from 76 in 1993 to 84 in 1996. The number of runways stayed the same, but changes at nearby Le Bourget Airport and other airspace infrastructure changes allowed independent operations between the two airports providing the capacity difference. Similar considerations occur in the US for areas such as the Washington TRACON and the New York TRACON.

Airport configuration also provides insight into airport usage. For example, a runway serving a mixed population of aircraft will have different results than a runway serving a homogenous category of aircraft. At airports with multiple runways, are the runways operated dependently or independently? Independent operations may allow far greater services whereas dependent operations may mean only one runway is being used at a time. Dependent and independent operations are reliant on the runway layout (separation, crossings, etc.). Are runways

[1] Rico, Frederic, " Air Traffic Management Constraints", Proceedings, ECAC/EU Dialogue with the European Air Transport Industry, Airport Capacity— Challenges for the Future, Salzubrg, April 1999

operating in mixed mode (arrival and departure) or single mode (arrival only or departure only)?

Breakdown of airport movements shows the ebb and flow of activities across a day. Little activity occurs in the early morning and late evening hours., This could be explained by:

- certain airports are under noise restrictions and therefore, the number of operations at this time are reduced due to airport curfew
- passengers prefer not travel at these hours.

Furthermore, airport movements are also dependent on passenger demand. Passenger demand can vary with seasons, with an increase in movements at certain times due to vacation travel.

5.1.2.1 Coordinated, Partially Coordinated and Non Coordinated Airports

European and US operations are both similar and different for airports. With respect to European Airports, they are:

- Fully coordinated airports where the slots allocated to aircraft operators as a result of the deliberations of the Airport Scheduling Committee are coordinated with CFMU in respect of departures. These slots are taken into account when the CFMU is in the Strategic Planning phase.
- Partially coordinated airports where the slots agreed by the Airport Scheduling Committee are not considered by CFMU. Request for clearance and CFMU regulation, if any, are on an "as required" basis.
- Non coordinated airports when traffic density requires neither an Airport Scheduling Committee nor special handling by CFMU.

Most of the large European airports are coordinated. This is ruled by European Commission Directive 95/93 of 18 January 1993, which in essence stipulates that due to demand and the increasing number of congested airports in the Community allocation of slots is necessary. The allocation of slots at congested airports should be based on neutral, transparent and non-discriminatory rules and it is considered that the requirement of neutrality is best guaranteed when the decision to co-ordinate an airport is taken by the Member State responsible for that airport on the basis of objective criteria.

The majority of US airports are non-coordinated or non-slot controlled airports with the exception of the four identified above. These four airports are located in high-density areas and fall within the boundaries of the US core airspace. Some airlines, airports and other advocates are working to increase flights operating at these airports. Several reasons are given

- opening up the coordinated airports will encourage competition,
- coordinated control at these airports is an outdated concept., With the advance of decision tools and automation these airports are capable of supporting more operations
- access to other airports may be limited due to operational caps related to night operations and local noise agreements.

5.1.2.2 Amsterdam Schiphol

Figure 1: Amsterdam Schiphol Airport Layout

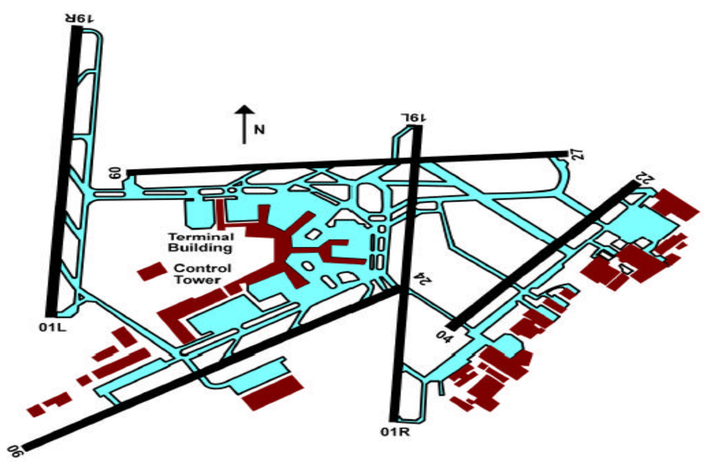
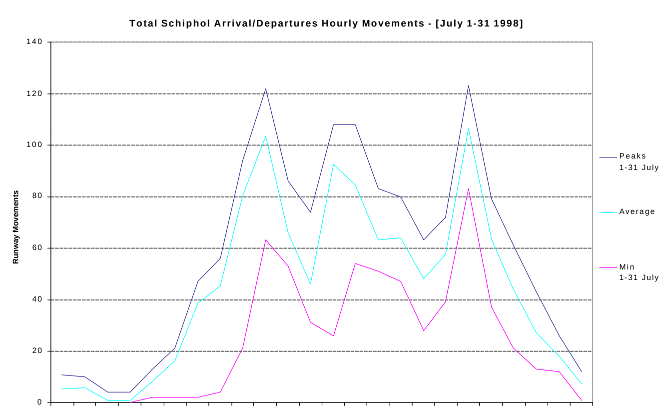


Figure 2: Amsterdam Schiphol Airport Movements



Airport Characteristics: 5 runways, capacity 100 movements per hour and 1 terminal, 96 gates, 33 stands and additional 19 stands for cargo operations.

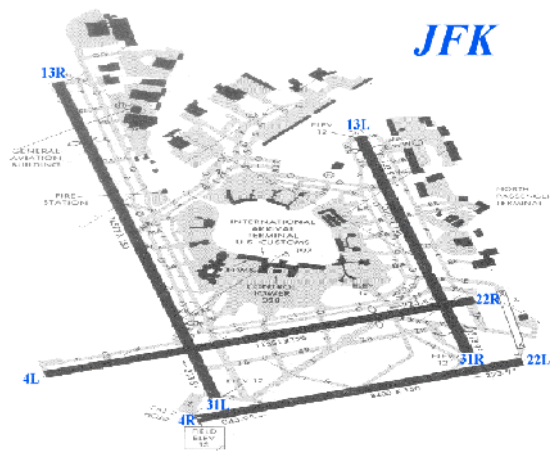
- Runways: 1L/19R (length 3300m/10827ft & width 45m/148ft), 1R/19L (length 3400m/11,155ft & width 45m/148ft), 6/24 (length 3490m/11,450ft & width 45m/148ft), 9/27 (length 3450m/11,319ft & width 45m/148ft), and 4/22 (length 2018m/6,621ft & width 45m/148ft).
- Annual Movements: 376,810 (1998)
- Average daily movements: 1,032 (1998)
- Declared Capacity: 100 movements per hour
- Environmental constraints will ultimately limit the capacity of the airport. Special SIDs are used between 23:00 and 07:00. There are limited landings on R/W22 and on converging runways there are limitations imposed in certain visibility and cloud base conditions.

5.1.2.3 New York – John F Kennedy International Airport

Airport Characteristics: 4 runways.

- Runway names and size: 4L/22R (length 11,351ft/3460m & width 150ft/46m), 4R/22L (length 8,400ft/2560m & width 150ft/46m), 13L/31R (length 10,000ft/3048m & width 150ft/46m), 13R/31L (length 14,572ft/4442m & width 150ft/46m), and 14/32 (length 2,560ft/780m & width 150ft/46m).
- Annual Movements: 352,305 (1997).
- Average Daily Movements: 982
- Declared Capacity: 92 per hour
- Departures:
- JFK launches the bulk of their departures between 4:00pm local and 7:00pm local.
- Arrivals:
- When weather and winds force JFK to utilize the ILS RWY13L approach, LGA must change to an ILS RWY13 approach. In this runway configuration, due to wake turbulence, LGA must use extra spacing between arrivals to allow for LGA heavy jet departures. This will decrease the arrival acceptance rate at LGA. If traffic demand is light, the runway change to take less than 5 minutes. If the traffic demand is heavy, the runway change will take between 15 and 20 minutes to allow N90 to clear the airspace prior to conducting operations for the ILS RWY13L approach at JFK. During this transition expect holding delays for JFK and LGA.

Figure 3: JFK Airport Layout



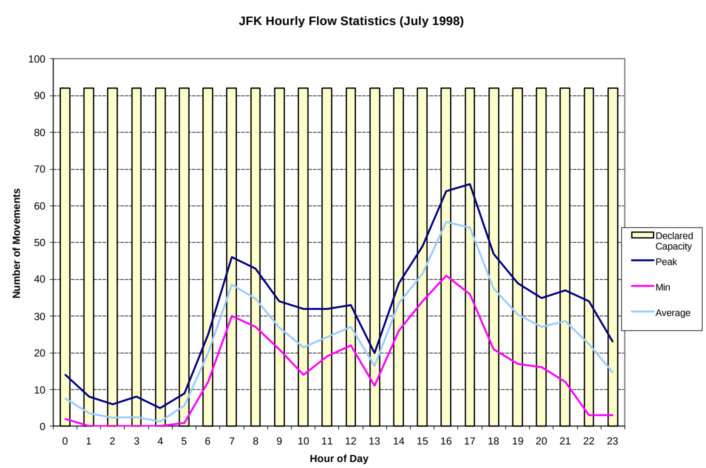


Figure 4: JFK Airport Movements

Airport Conclusion

The comparison study cannot find major systemic differences in the manner in which airports and runways are managed. The negotiation of slots versus the market driven schedule provides the appearance of uniform demand versus peak operations. The number of operations scheduled and manner in which the schedule is said to be set - IMC versus VMC - becomes less significant as sliding peak hours are examined, that is, when the peak consecutive

60-minute performance is compared versus the hourly count.

Airport	Number of Runways	Runway Capacity (1996)	Annual Movements 1996
Gatwick	1	42	394,104
LGA	2	76	342,618
CDG	0.02	84	367,222
IAD	3	120	330,439
Schiphol	5	131	303,000
DTW	5	150	531,098
EWR	3	100	443,431
PIT	4	162	447,436
Averages			
European	2.0066667	86	354,775
U.S.	3.4	101	419,004

Table 1: Comparison of Europe and US Airports

We see that the standard method of examining performance is not adequate for overall comparison. The hourly count approach most commonly used masks the maximum performance and it is clear that this will be the case in the examination of most airports. This is an important point, which is highlighted by this comparison and should be considered further in the joint development of measures of operational performance.

5.2 En-Route Airspace

A subset of airspace volume was selected for the comparison exercise.

Airspace assessment includes the clearer definition of sectors or airspace volume, staffing or controller team, and throughput. How is operation of US airspace similar to and different from operation of European airspace?

In addition to throughput, density and complexity are other indicators for controller workload. Traffic density and complexity may indicate the controller team efforts for monitoring, resolving potential conflicts, and maintaining flow management. What are the appropriate measures and metrics for density and complexity?

5.2.1 Center and Sector Statistics

Centers - A center is made up of many sectors. Table 4 lists the centers and sectors in the core area. In the area of comparison there is almost twice the number of centers in Europe than in the US. Analysis shows the number of sectors per center is greater in the US than in Europe. European centers are often defined by national boundaries. Are there other factors involved? What are the factors that influence the US centers (e.g., boundaries, characteristics of traffic, etc.)?

In Europe the "volume" of an Air traffic Control Center (ACC) is calculated by multiplying the area of the ACC, expressed in square nautical miles, by the number of available flight levels within the ACC. Indeed, the introduction of Reduced Vertical Separation Minima (RVSM), will increase the number of available flight levels within Upper Airspace and will have the effect of increasing the volume of ACCs.

In the US, the center volume is roughly calculated based on the center boundaries at Flight Level (FL) 240 and expanded to cover from FL 180 to FL 600.

No direct comparison of ACC volumes could be made. However, taken by itself, the volume of an ACC is no indicator of how busy or complex the ACC may be. On the other hand, by adding the number of sectors, deductions may be made on traffic density and complexity of the en-route structure. As an example, within the UK FIR Scottish ACC has a volume of 5,521,018 with 10 sectors, while London has a volume of 2,144,174 with 29 sectors; less than half the volume with 3 times as many sectors.

Data for individual sector volumes were not easily accessible, so, an average sector volume based on ACC volume divided by the number of sectors has been used for comparison purposes.

Total number of flights is also available for each center along with the average transit time for the sector. As Table 5 shows, the transit time for European centers is often smaller than the transit time for US centers. London Center in Europe is similar to New York Center in the US in number of traffic, type of traffic, and average transit time.

Further assessment of aircraft activities shows the average flight time in the US is 1 hour and 23 minutes and the average flight length is 470nm. Average IFR flight length within the ECAC countries was 470 nautical miles and 1 hr and 20 minutes in duration. Based on the numbers in Table 5, an average flight in the US crosses three center boundaries, and five center boundaries in Europe. In the US, this is significant since the process of managing aircraft into the upper flow can last 200 miles (based on Standard Instrument Departures (SIDs)) and the process of sequencing and spacing for arrivals often extends beyond the 400 mile mark. For a major airport such as Chicago O'Hare the process extends into the second tier of centers, that is 800 miles and beyond. These impacts are discussed in greater detail in the Traffic Management section.

5.2.1.1 Declared Sector Capacity

In Europe, an important factor is the declared capacity of the sector. Qualifications of controllers and the progress of trainees can also have a significant effect on traffic throughput. Furthermore, as working practices, especially in the manning configuration, vary not only from country to country but perhaps also from unit to unit, assessment of workload for comparative purposes is very difficult. In addition, confidentiality and other sensitive issues relative to local work practices and procedures can cause difficulties in compiling meaningful data.

Sector capacity is the measurement of throughput per hour for each sector.

In Europe, an hourly declared sector capacity is the number of aircraft that a sector can accept (entry) in a 60 minute period and for CFMU is the trigger to impose, or not, flow regulations (maximum number of aircraft that a sector can sustain). The value is used by the CFMU for Flow Management. In the US, hourly declared sector capacity is not used.

In the US, an hourly sector capacity number for each sector is not available. Instead, a negotiated Monitor Alert Threshold (MAT) value is used. The MAT number for each sector is based on the sector size, the type of traffic, and the complexity of the traffic. The MAT number is an indication of how much traffic a controller can safely work at any one time.

The impact of airspace design and sector capacity has a large influence on traffic flow. Traffic management in Europe and the US is discussed in greater detail in the next section.

5.2.1.2 Comparative Statistics

A detail assessment at the sector levels includes the analysis of declared sector capacity in Europe and traffic count and sector loading.

- Instantaneous Count is the maximum number of flights observed within the sector at any time during a 15-minute period.
- Daily Entry Rate (DER) in both ACC’s and sectors (Note that there is no difference in DER between requested and regulated flight plan data).
- Maximum Instantaneous Count in each sector is based on requested and regulated flight plan data**.** The requested flight plan data is not available in the US.
- The traffic is divided into seven different classes in Europe but fewer in the US. These classes are:
  - Cruise (Europe & US),
  - Climb (Europe & US),
  - Descend (Europe & US),
  - Climb_Cruise (Europe),
  - Cruise_Descend, (Europe),
  - Climb_Descend (Europe), and
  - Climb_Cruise_Descend (Europe).
- Graphical presentation of Declared Sector Capacity, Instantaneous Count and Sliding Hourly Entry Rate (SHER). SHER is the number of flights entering the sector within one hour. This figure is calculated every 15 minutes. It is calculated by summing the number of aircraft entering 45 minutes before and 15 minutes after the reference time. An example of a graphical presentation is given below in Figure 7, Figure 8, and Figure 9.

Frankfurt sector NR2 has a declared capacity of 46 aircraft. At 0600 the SHER is 56 (which means that 56 aircraft entered the sector during the period 0515 to 0615). At 0530 can be identified the maximum Instantaneous Count of 15 flights within the sector at the same time.

In the second example it can be seen that the Lydd Sector at London exceeded Declared Capacity (33) several times. Indeed, from 06:00 to 20:30 the sector was close to or exceeding capacity. The DER was 624 aircraft. The Instantaneous Count was reasonably steady and below 10 for most of the busy period. It is interesting to note that Requested Flights and Regulated Flights are exactly the same. This could be that, while actual traffic was exceeding capacity, the number of aircraft in the sector at any one time (Instantaneous Count) was within the capacity of the controllers. Whilst this could indicate that declared sector capacity is set at a level which guarantees that traffic will be manageable in all circumstances in spite of uncertainties in the system which may result in actual traffic being greater than that regulated. Only 13% of the 624 aircraft were in the cruise. The remaining 87% were Evolving Traffic with 23% climbing and 42% descending.

For comparison purposes sectors from New York Center were chosen (Figure 9). Statistics that match the European formulation were not available for these sectors. However hourly flight strip counts that are an indicator of throughput were available. These numbers are based on Tuesday for a six-month period from October through March. When one compares these sectors (and others not shown) there are similar throughput rates.

There are within the US sectors that have higher throughput rates. These sectors are designed to be one-way to accommodate traffic flows which are same direction but cross for instance a west to east flow and a northwest to southeast flow. In these sectors the opposite flow flight levels are not used for normal directional flow but instead are kept for opposite directions crossings. One such sector is described below.

In the US, sector 49 is an en route sector that has an Instantaneous Sector Capacity of 19 (MAT + 20%). The trend shows traffic exceeds capacity in the latter part of the day. Approximately 87% of the flights in Sector 49 are cruising, 9% are climbing, and 4% are descending. Sector 49 has an average throughput of 45 per hour and a maximum of 102.

5.2.2 En-route Airspace Conclusion

When comparing like with like there are no striking differences. There is no great difference in throughput or staffing procedures. This is good, for when coupled with the airport results, this says that we can be reasonably assured that we are describing systems that are not substantially different.

It does not, however, provide explanations of why at the strategic flow level the Europeans opt for the CFMU versus the apparently more ad hoc system used in the US,or the US use single direction sectors. This leads us into the next section where we examine the flow objectives and the processes employed to meet these objectives.

5.3 Traffic Management

5.3.1 Traffic Management Phases

The focus of the airspace comparison section was the examination of the management of individual flights. Although the statistics are aggregate, the snapshots into airspace focus on the aircraft and the individual flight as it moves through the system - the transit time of the flight, the phase of flight the aircraft is in, the instantaneous count of flights, etc. The values measured can give indications of general health from one day to the next. The values do not provide insight into the underlying objectives that the ATC system had for these flights. The problem with extrapolating from these statistics to a definitive comparison occurs whether one is comparing one sector to the next in the same center as well as sectors from opposite sides of the Atlantic.

As a result, in the course of conducting the comparison, the team had to go from measurement to hypothesis in order to try to use the statistics as a means of comparison. In developing the hypotheses, it became clear that an aircraft is subject not only to the individual phases of flights departure cruise arrival, etc but also to a series of traffic management phases. The phases, shown in Figure 10, are moving from left to right in the figure:

- The **Ramp Management Phase** moves the aircraft in and out of the gates.
- The **Airport Surface Management Phase** takes aircraft in departure from the ramp to the departure queue.
- The **Departure Management Phase** manages the departure queue to launch aircraft from the queue(s) into the airspace.
- The **Dispersion Management Phase**, which as its name implies, has the objective to get flight up and out of the terminal into the en-route structure.

- The **En-route Management Phase** shows the aircraft at altitude and moving towards their destinations, but it is not yet subject to actions associated with their arrival.
- The **Collection Management Phase** sequences and spaces aircraft to bring them into the terminal area.
- The **Arrival Management Phase** assigns aircraft to runways and gets them onto the surface.
- The **Airport Surface Management Phase** gets the aircraft off the runways and moves the aircraft to the ramp.
- The **Ramp Management Phase** works to get them into gates.

An assessment can be made of the ATM system and the related Traffic Management Phases.

1. Gate-to-gate is not equivalent to dropping an aircraft in at one end, turning the crank and popping it out at the other. It is the consideration of all phases as interrelated elements of a network. Traffic is mixed in size and direction so the phases need to be scaled to manage the uncertainty. The chokepoints in the system flow should only be the natural physical points i.e. the concrete infrastructure runways, taxiways and gates.
2. The phases are not disjointed. In the Newark arrival case, aircraft departing Washington will be in both the departure management phase and the collection management phase at the same time. In fact, that is probably the most common occurrence. A flight that is required to fit into a specific slot in the en-route may be in the airport surface management, the departure management and the dispersion phases simultaneously.
3. The phases need to be managed to ensure that a preceding phase does not overload a succeeding phase.
4. Aircraft are not segregated by traffic management phases. Some aircraft in cruise might be subject only to en-route management while others in the same sector might already be part of a sequence and undergoing spacing for the collection management phase. These characteristics are considered by the controller as conflict probing and resolution planning are conducted. It is also a level of complexity currently not considered by most tools.
5. The technique used in the Newark arrival example is the imposition of miles in trail on this arrival route to ensure that the load over the arrival fixes will not exceed the terminal and airport rates.

Herein may lie the differences that are seen between what is characterized as the ad hoc US system versus the more structured CFMU control flow in Europe. There has always been the characterization that the bottleneck in Europe is the en route and the bottleneck in the US is the airports. Characterizing the flow based on the traffic management phases provides insight into what that may actually mean. Comparing things airport by airport, sector by sector did not show great differences in throughput. The airport by airport comparison showed mainly differences in scheduling philosophies and infrastructure size.

In neither environment is there a problem in filling up the airspace, especially close to the airports (with close being a subjective term for which a value of 200 nautical miles (nm) is not unreasonable). The differences seem to be in the techniques available for managing flow. The techniques have a relationship to the scope of information, the span of influence available in the technique and the degree of interactions between flows or at least the availability of some elements of the overall flow with greater independence from the rest of the traffic. In the US, requiring Miles-In-Trail (MIT) restrictions on internal center sectors as well and especially those in the previous center can achieve the management of flow. The same influence is not possible in Europe.

The inability to extend influence back into the en-route results in an imbalance of demand and capacity close to the airport and will require large amounts of holding. Considering the example from the Rico paper, this is equivalent to free flowing a rate of 90 aircraft up to the terminal boundary and then trying to manage it with only a 60 aircraft outflow. It is clear that any airspace buffer will soon be exhausted. Without the ability to manage the flow in the en-route through controller imposed restrictions, the alternative is to manage the flow at the source, hence the CFMU.

The restriction method is not without problems. First, as can be seen in the Newark example, the technique requires a volume of airspace where aircraft can be staged through vectoring and other techniques to space and sequence the flow. As traffic volumes grow in general, the buffer airspace may become overloaded with other traffic. The en-route traffic problems experienced in the US in the Cleveland and Indianapolis Centers may be related to this and is a subject of follow on analysis.

Second, the method of metering to fixes and not managing flow to the airport results in inefficiencies and under utilization of runways. This is the subject of much of the research represented in NASA's Traffic Management Advisor. A major component of its utility will be extending accurate arrival trajectory modeling across center boundaries and providing individual flight strategies to upstream sectors regardless of facility.

Finally, there is always the problem of the close in flight. Both the restriction method and the improved Traffic Management Advisor method work best when the flow consists mainly of aircraft that are airborne at the time of first management. When the flow has a large component of short flights as may be represented in the core of Europe or in the Washington to New York flows, the techniques become more difficult and less efficient.

6 Conclusion

The comparison exercise has led to increased understanding on both sides of the ocean into the vagaries associated with shared knowledge. We investigated the IMC versus VMC operations Europe to US. The common knowledge provided the starting point, but the subtleties of access, negotiations and politics are missing in that shared knowledge. When these components are added, no great difference on a runway by runway basis could be derived.

In the airspace, when staffing practices and like sectors are compared once again the similarities outweigh differences. It is only when we began to consider very specialised sectors/practices that some specific conclusions can be drawn. In addition, it is also when we considered the impact of the overall traffic flow that we began to ascertain why some decisions versus others are made. It is the tool options available to meet aggregate goals of the Air Navigation Systems that need the investigation. It is scope of information and span of influence that begin to provide insight into our existing and future concepts.

To this end, the team identified the Traffic Management Phases of flights. When we say gate-to-gate we often think of individual flights and the individual flight states. However, on reflection gate-to-gate is not about individual flights but flow. It is a concept that recognizes the network effects linking all decisions from departure to destination and attempts to choreograph the mass of flights into an efficient aggregate.

We have only begun to scratch the richness that this view into the concept provides. This framework improves our ability to tie together, concept, services and performance. It also provides the context in which we can further mutually define the ANS global concept.

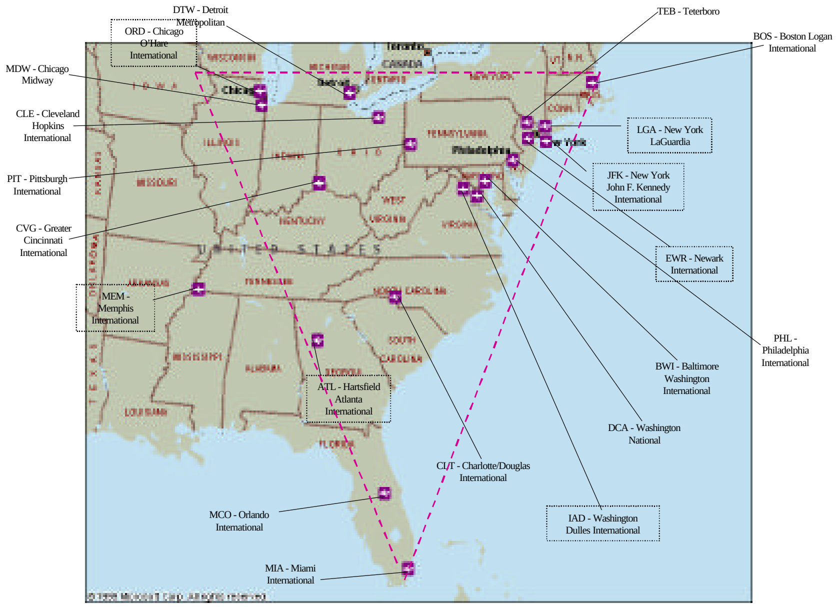


Figure 5: US Core Airspace

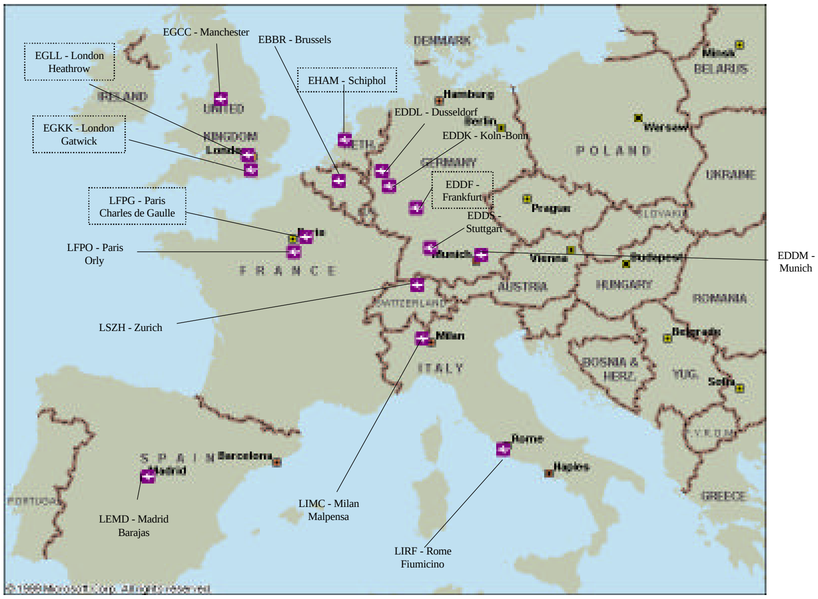


Figure 6: European Core Airspace

Atlanta

Operator	% of Total
DELTA AIR LINES INC (DAL)	62.6%
ATLANTIC SOUTHEAST AIRLINE (ASE)	11.9%
VALUJET AIRLINES (VJA)	8.2%
CONTINENTAL AIRLINES (COA)	2.5%
AMERICAN AIRLINES INC (AAL)	2.3%
Total	87.46%

Charles De Gaulle

Operator	% of Total
Air France (AFR)	49.68%
Deutsche Lufthansa German Airlines (DLH)	5.42%
British Airways (BAW)	4.39%
Alitalia (AZA)	3.04%
(ARP)	2.19%
Total	64.72%

Heathrow

Operator	% of Total
Bristish Airways (BAW)	31.06%
British Midland (BMA)	13.63%
British Airways Shuttle ()	5.90%
Lufthansa ()	4.00%
Aer Lingus (EIN)	3.23%
Total	57.82%

Newark

Operator	% of Total
CONTINENTAL AIRLINES (COA)	57.3%
UNITED AIR LINES INC. (UAL)	6.5%
US AIRWAYS (USA)	5.8%
AMERICAN AIRLINES INC (AAL)	5.6%
DELTA AIR LINES INC (DAL)	3.7%
Total	78.88%

O'Hare

Operator	% of Total
UNITED AIR LINES INC. (UAL)	42.9%
AMERICAN AIRLINES INC (AAL)	39.7%
DELTA AIR LINES INC (DAL)	2.4%
NORTHWEST ORIENT AIRLINES (NWA)	2.3%
US AIRWAYS (USA)	1.8%
Total	89.04%

Schiphol

Operator	% of Total
Koninklijke Luchtvaart Maatschappij (KLM)	37.99%
Air UK Ltd. (KLM UK)	11.23%
Eurowings AG. (EWG)	6.55%
Transavia Holland B.V. (TRA)	4.33%
Martinair Holland B.V. (MPH)	2.24%
Total	62.34%

Table 2 : Major Operators at Top European and US Airports

Airport	Peak Daily Movements	Total Annual Movements	Heavy	Medium	Light
New York - John F Kenedy (JFK)	982	342,814	38.33%	57.98%	3.69%
London - Heathrow (LHR)	1279	451,073	33.55%	66.54%	0.89%
Germany - Frankfurt (FRA)	Not available	415,686	33.00%	66.00%	1.00%
London - Gatwick (LGW)	783	251,291	20.65%	75.00%	4.25%
Amsterdam - Schiphol (SPL)	1032	376,810	18.87%	77.80%	3.33%
Paris - Charles De Gualle (CDG)	1200	367,222*	18.17%	81.48%	0.24%
Atlanta - Hartfield (ATL)	2298	817,492	14.89%	83.34%	1.78%
Washington - Dulles (IAD)	1124	379,621	14.54%	77.80%	7.67%
New York - Newark (EWR)	1264	444,370	12.20%	79.73%	8.07%
Chicago - O'Hare (ORD)	2536	887,551	11.16%	76.16%	12.68%
New York - La Guardia (LGA)	1009	361,135	5.66%	74.56%	19.77%
Memphis (MEM)	717	252,941	1.80%	87.72%	10.48%

Table 3: Summary of Aircraft Categories by Wake Vortex

European Centres

Centres	Volume (sq nm x fl)	Number of Sectors		Centres	Volume (sq nm x fl)	Number of Sectors
Amsterdam	671,106	6		Brussels	243,327	6
Dusseldorf	304,574	11		Frankfurt	593,032	18
Geneva	307,234	6		Karlsruhe	445,373	17
London	2,144,174	29		Maastricht	1,112,142	10
Manchester	349,097	3		Marseilles (Aix)	2,829,551	22
Munich	655,639	11		Paris	1,681,904	19
Reims	670,821	11		Vienna	2,807,077	14
Zurich	438,687	7				

US Centers

Centers	Volume (sq nm x fl)*	Number of Sectors		Centers	Volume (sq nm x fl)*	Number of Sectors
Atlanta (ZTL)	2,466,960	45		Boston (ZBW)	3,063,002	30
Chicago (ZAU)	2,044,424	46		Cleveland (ZOB)	1,817,732	43
Indianapolis (ZID)	1,903,233	35		Jacksonville (ZJX)	3,905,773	37
Miami (ZMA)	9,618,567	30		New York (ZNY)	654,440	31
Washington (ZDC)	3,226,551	43				

*Note - up to 60,000 ft.

Table 4 : European and US Centers

European Centres

Centres	Avg. Transit Time (per ACC) in minutes	Total Movements for Sept 96	Centres	Avg. Transit Time (per ACC) in minutes	Total Movements for Sept 96
Amsterdam	8.6	35,553	**Brussels**	10.5	42,631
Dusseldorf	19.1	41,007	**Frankfurt**	11.7	62,278
Geneva	11.3	43,574	**Karlsruhe**	18.9	60,129
London	20.1	113,203	**Maastricht**	20.1	80,057
Manchester	12.3	28,779	**Marseilles**	27	61,705
Munich	14.6	62,547	**Paris**	14.3	90,850
Reims	19.4	55,047	**Vienna**	19.6	43,402
Zurich	12.1	51,966			

US Centers

Centers	Avg. Transit Time (per ACC) in minutes	Total Movements for Sept 96	Centers	Avg. Transit Time (per ACC) in minutes	Total Movements for Sept 96
ZAU (Chicago)	29.7	382,320	**ZBW (Boston)**	31.3	105,540
ZDC (Wash. DC)	32	216,360	**ZID (Indianapolis)**	28.6	367,230
ZJX (Jacksonville FL)	36.2	236,640	**ZMA (Miami)**	40.6	124,530
ZNY (New York)	22.9	128,010	**ZOB (Cleveland)**	26.8	342,000
ZTL (Atlanta)	30	340,770			

Table 5: Total Number of Flights for September 1996

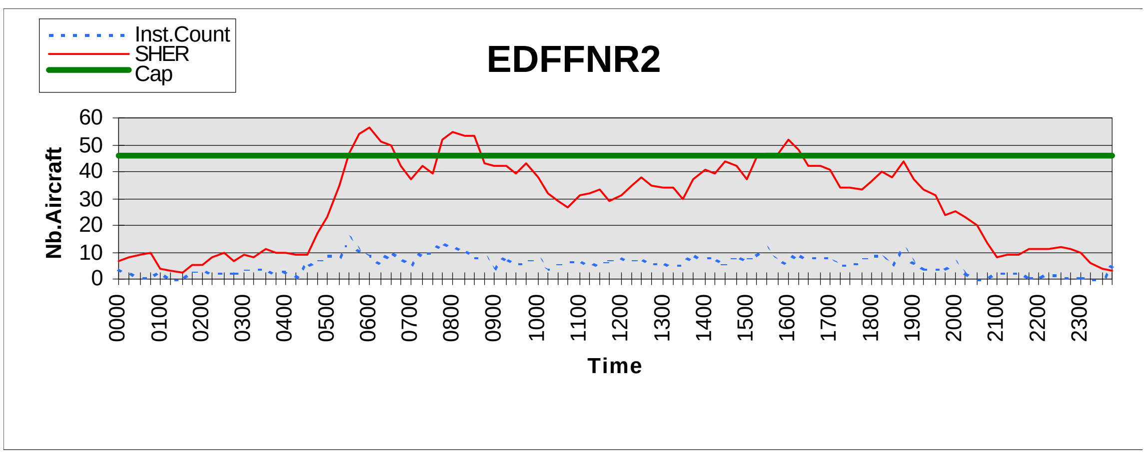


Figure 7: Sector NRe (Frankfurt)

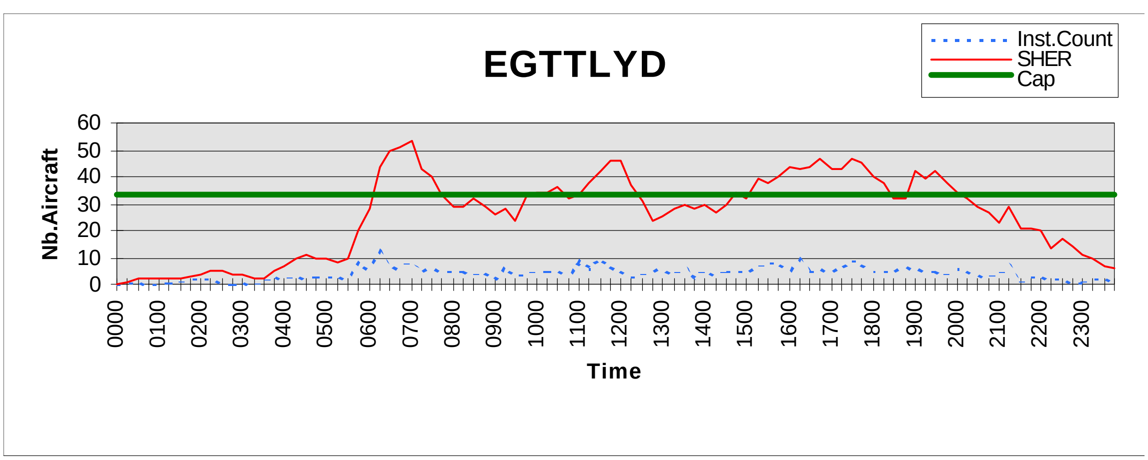


Figure 8: Lydd Sector - Requested & regulated

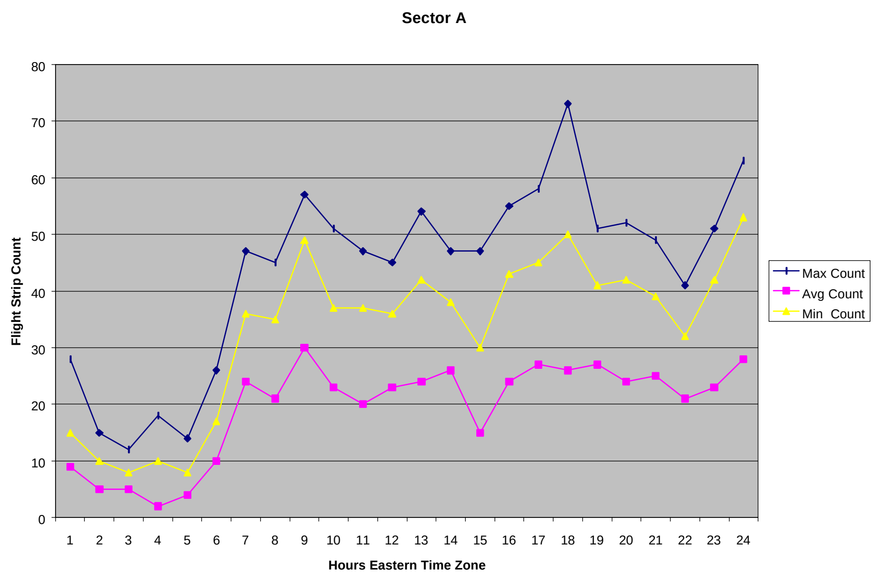


Figure 9: New York Sector A

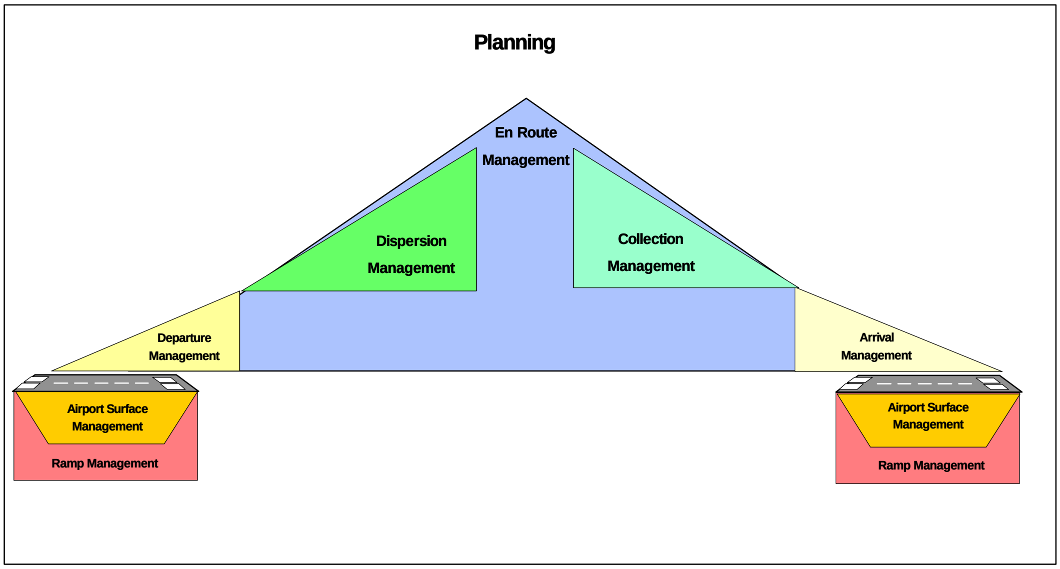


Figure 10: Traffic Management Phases

7 Biography

Steve Bradford is the Manager of the NAS Concept Development Branch in the Office of System Architecture and Investment Analysis (ASD). In this role he has participated in the development of the ATS 2005 Operational Concept and the RTCA Joint Government/Industry Operational Concept. His organization is also responsible for leading the effort to validate the future concepts, develop the FAA's ATC Information Architecture and leads co-operative modeling efforts with the European Community via joint agreements with Eurocontrol. Prior to his current position, Mr. Bradford was a team leader in the

Investment Analysis and Operations Research Organization where he lead several simulation and analytic software development efforts, and conducted early analysis of Free Flight Concepts. From 1987 to 1991 he worked for CACI, Inc. where he led the SIMMOD model development and taught simulation language and modeling courses. He has also worked for the US Navy developing logistic planning models.

Diana Liang works for the Office of System Architecture and Investment Analysis in the NAS Concept Development Branch. She is responsible for developing Modeling Tools and Fast-Time Simulations to support NAS Operational Concepts. This work includes several models she is developing jointly with NASA and cooperative efforts with Europe via Eurocontrol. Prior to working for ASD, Ms. Liang worked in the Office of Energy and Environment for two years as the lead for the Emissions and Dispersion Modeling System (EDMS), updated the FAA's Air Quality Handbook and reviewed Environmental Impact Statements related to emissions. Ms. Liang holds a BS in Computer Science from George Washington University.

William (Bill) Marnane who has an operational background as a Air Traffic Controller is employed in the Strategy, Concept and System Unit (SCSU) at EUROCONTROL HQ, Brussels. As a contribution to the FAA/EUROCONTROL Action Plan 2 Mr Marnane collated the European data to enable comparison between US and European Airspace and the traffic therein. Previous responsibilities included development, within the context of the ATM 2000+ Strategy, of the Surveillance Strategy for ECAC, operational input to the Survey of Mediterranean Airspace for ADS (SMAA) which wa a joint venture between EUROCONTROL, Italy, Spain France and Greece. He currently supports the development of the European Air Traffic Management Programme (EATMP) Strategic Performance Framework within the SCSU. In addition, Mr Marnane is Secretary of the SCS Team whose responsibilities include making proposals for development and maintenance of the overall EATMP strategy, concept, roadmap and architecture.